Diameter Caps for Thinning Southwestern Ponderosa Pine Forests: Viewpoints, Effects, and Tradeoffs

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ABSTRACT

Upper size limits of trees allowed to be cut, termed diameter caps, have resulted in polarization, litigation, and delays and alterations to thinning projects in many western forests. Using southwestern ponderosa pine forests as an example, we summarize viewpoints on caps, simulate effects of caps on thinning prescriptions, and provide examples of ecosystem-level tradeoffs of leaving extra trees during thinning projects. The importance placed on trees versus other ecosystem components primarily differentiates those who support caps and those who do not. We conclude that diameter caps may enhance some ecosystem components, such as densities of large trees, but they negatively impact many nontree components.

Keywords: ecological restoration, treatment prescription, fuel reduction, ecosystem management

Tree densities have increased sharply in many western frequent-fire forests since the late 1800s because of fire exclusion and other factors (Lynch et al. 2000, Allen et al. 2002). In southwestern ponderosa pine (*Pinus ponderosa*) forests, for example, there is widespread agreement that mechanical tree thinning is necessary to restore ecosystem health, reduce crown fire hazards, and make human habitations safer (Covington et al. 1997, Allen et al. 2002, Nowicki and George 2004). There also is agreement that, regardless of their size, old trees that were established before Euro-American settlement ("presettlement") in the late 1800s generally should be conserved. Consensus disintegrates, however, when attention turns to thinning young, postsettlement trees of relatively large diameter (often defined as $>$16 in.). Some individuals believe that thinning these large, young trees is sometimes necessary to enhance ecosystem health (Coughlan 2003), whereas others argue that large trees, regardless of age, generally should be retained (Allen et al. 2002, Nowicki and George 2004). To retain all large trees, some people support a policy of diameter caps, defined as upper size limits of trees allowed to be cut. Sizes of caps in ponderosa pine forests have ranged from as small as 5 in. to greater than 18 in. (Coughlan 2003, Fulé et al. 2006). Caps are imposed frequently by the US Forest Service, National Park Service, and other organizations, partly to show that fuel reduction and restoration thinning projects are not simply logging operations in an attempt to gain support for these projects (Larson and Mirth 2001, Coughlan 2003). Nevertheless, dissent about diameter caps has resulted in delays and modifications of numerous fuel reduction and ecological restoration projects in western forests (Coughlan 2003).

Peer-reviewed scientific publications on diameter caps are rare (Larson and Mirth 2001, Coughlan 2003). We suggest that disagreements about caps are frequently based on personal opinion and may be concentrated on trees at the expense of other important ecosystem components. In this article, using southwestern ponderosa pine forests as an example, we first provide an overview of the viewpoints on diameter caps. Next, we use stem maps from a field study in northern Arizona to assess effects of caps on pine densities and patterns in a simulated thinning prescription. Finally, we summarize anticipated tradeoffs of diameter caps for several ecosystem components and economics based on peer-reviewed literature. Our focus is on 16-in. caps, because this cap size has been widely proposed in the Southwest, although similar analyses could be applied to caps of any size. We hope that these analyses will broaden thinking on diameter caps to more fully include ecosystem considerations beyond the trees themselves. In addition, these analyses may be useful to stakeholders and policy makers concerned with implementing urgently needed thinning projects.

Viewpoints

Viewpoints on 16-in.-diameter caps generally fall into three categories: supportive, neutral, or opposed (Table 1). Depend-

Table 1. Summary of viewpoints about diameter caps and commonly used arguments to support the viewpoints.[a]

Supportive
Large trees are rare so they should be retained regardless of age or location
Large trees are ecologically valuable, such as for snag formation
Large trees are fire resistant so their removal is not needed for fuel reduction
Selling large trees should not pay restoration project costs
Economics should not drive restoration and fuel reduction projects
Neutral
Because often there are few young, large trees, they may as well be retained
Leaving a few extra large trees probably has little ecological effect
Diameter caps may allow projects to avoid litigation
Opposed
Removing young, large trees is sometimes necessary to restore openings
Retaining too many excess trees compromises other ecosystem components
Trees are inflexibly retained even if the stands that result fail to achieve objectives
Leaving excess trees necessitates future heavy thinnings and multiple entries
Residual trees grow rapidly after thinning so large trees accrue quickly
Selling young, large trees offsets project costs and funds follow-up management
Selling young, large trees may allow contracts and projects to proceed

[a] Viewpoints and reasons cited in support of the viewpoints are based primarily on Allen et al. (2002), Coughlan (2003), Fiedler et al. (1999), Fulé et al. (2006), Larson and Mirth (2001), Lynch et al. (2000), and Nowicki and George (2004).

ing on the individual, advocates of these viewpoints cite one or several reasons to support their views. Supporters believe that large trees have decreased in density because of past logging, so all extant large trees regardless of age should be retained during forest thinning (Nowicki and George 2004). Supporters also believe that these large trees represent the next cohort of old trees, are important habitat features, will result in snag formation important for wildlife, and do not need to be removed to reduce crown fire hazards. In addition, underlying support for caps is the concern that without caps, forest thinning under veils of restoration or fuel reduction might be motivated by economics rather than ecology. This concern likely emanates from distrust of public land-management agencies (Coughlan 2003).

Neutral viewpoints reflect the perspective that because many sites contain few young, large trees, retaining these trees has little immediate ecological or economic effect (Table 1). Holders of this viewpoint also

Figure 1. The large tree in the bottom center of the top photo is 23 in. in diameter but only approximately 95 years old. The nearest presettlement evidence is 34 ft away from this postsettlement tree, indicating that the tree likely invaded a historical meadow opening. This young tree would be retained in thinning projects with 16-in.-diameter caps. The bottom photo shows presettlement evidence (gray stump) surrounded by small postsettlement trees. These photos illustrate a tradeoff of diameter caps: retaining the large postsettlement tree in the top photo provides immediate large-tree structure, yet precludes restoration of a historical opening. Retaining the small trees around the presettlement stump in the photo at the bottom would maintain historical locations of trees and openings, but the small trees will take longer to develop large-tree characteristics. It should be recognized, however, that on this site with high densities of postsettlement ≥16-in. trees (42/ac), large openings probably cannot be reestablished under any thinning prescription with a 16-in. cap (Figure 2a). (Photos by S.R. Abella, Jan. 17, 2006, Coconino National Forest, northern Arizona [35°15′50″ N, 111°40′40″ W]).

believe that caps are beneficial if they prevent thinning projects from being delayed by litigation.

However, opponents of diameter caps also have several reasons they believe that caps should not be imposed (Table 1). For example, they believe that large, young trees sometimes need to be removed to restore canopy openings (Figure 1). Large, young trees also may need to be cut if these trees sharply exceed presettlement densities, resulting in unsustainable stands still susceptible to crown fire after thinning. In addition, opponents believe that residual trees grow rapidly after restoration thinning, which is supported by published research (Skov et al. 2005), so that caps may not greatly benefit the development of large trees. Another argument used against caps is that harvesting some large, young trees can offset the financial costs of restoration and fuel reduction projects, allowing these projects to proceed more quickly and encompass greater area.

Simulating Effects

To understand effects of 16-in.-diameter caps on a thinning prescription, we stem-mapped a 2.47-ac (1 ha), 328 × 328 ft plot in 2004 on each of eight sites studied as part of previous research (Abella and Covington 2006). Plots were located in ponderosa pine forests in the Coconino National Forest and Northern Arizona University Centennial Forest near the City of Flagstaff in northern Arizona. These plots were not intended to encompass a complete array of stand conditions in this region, but plots did cover a representative range of stand densities (12–412 live pine/ac) and structures (Abella and Covington 2006). Using tapes laid out to create 100, 0.025-ac (33 × 33 ft) cells on each plot, we mapped all live trees and evidence of presettlement tree locations (stumps, stump holes, logs, and snags) to the nearest 0.3 ft in an *x*,*y*-coordinate system. We identified presettlement evidence following methods in Fulé et al. (1997). We chose the year 1880 to represent settlement and fire-regime disruption on these plots, based on previous research in the study area that has recorded disruption dates ranging from the mid-1870s to the mid-1880s (Covington et al. 1997, Fulé et al. 1997).

We used the maps to simulate a restoration thinning prescription with and without a 16-in.-diameter cap. This prescription is designed to reduce tree densities to within an approximate range of historical variability, while reestablishing presettlement tree patterns (Fulé et al. 2001). In our simulations, 1.5 postsettlement trees ≥16 in. were retained within 30 ft of each dead presettlement tree, or three postsettlement trees <16 in. were retained if larger trees were not available. This replacement ratio is intended to account for possible tree mortality from treatment operations (Covington et al. 1997, Fulé et al. 2001). All living presettlement trees were retained.

We found that diameter caps affected postthinning stand conditions the most on plots containing many ≥16-in. postsettlement trees and where these trees were not located close enough to presettlement evidence to be used as replacements. Thinning simulation results are illustrated in Figure 2 for two plots exemplifying different levels of cap influences. On a plot containing a high density (42/ac) of postsettlement trees ≥16-in., for example, the cap resulted in the retention of an extra 28 trees/ac ≥16 in. compared with cap-free thinning. Because the cap-free thinning grouped retained trees around presettlement evidence, inevitably the cap led to the retention of additional trees within groups or the retention of trees occurring in openings away from presettlement evidence. These extra trees limited the reestablishment of historical openings or any openings (Figure 2a). In addition to higher densities, residual basal area also was sharply higher in the cap-constrained prescription (87 ft^2/ac) than in the cap-free prescription (39 ft^2/ac). Another plot provided an example where 16-in. caps had little effect because only nine postsettlement ≥16-in. trees/acre occurred on this plot. All but one of these trees could be used to replace dead presettlement trees (Figures 2b and 3).

The restoration prescription based on presettlement tree locations illustrated in this article (Figure 2) is only one of many possible thinning prescriptions that could be used, with or without diameter caps. For example, Allen et al. (2002) suggested using existing structure, rather than presettlement tree locations, to guide thinning and rapidly reestablish groups of large trees. The prescription based on presettlement tree locations differs from this structural approach only by emphasizing the retention of trees near presettlement evidence and the reestablishment of historical locations of canopy openings (Figure 1). However, neither of these approaches, when constrained by a diameter cap, could establish canopy openings on sites containing high densities of ≥16-in. trees (Figure 2). Caps may similarly affect other fuel reduction and thinning prescriptions, such as those based on meeting target basal areas. In cap-constrained basal area cutting, the basal area of ≥16-in. trees sets the minimum level of basal area remaining after thinning, whether or not that level meets management objectives.

Our simulations illustrate that influences of caps likely change across the landscape with variations in abiotic site factors, disturbance history, and past management that affect tree size, density, and pattern within stands to be thinned. The next section provides examples of long-term tradeoffs for multiple ecosystem components of imposing or not imposing diameter caps on southwestern ponderosa pine thinning projects.

Ecosystem and Economic Tradeoffs

Canopy Openings. Canopy openings and meadows are key habitat for many organisms in ponderosa pine forests, but these habitats have been severely reduced during the 1900s by invasion of postsettlement trees (Moore and Huffman 2004). Caps affect canopy openings by precluding their reestablishment altogether or by causing the spatial locations of openings to shift away from their historical locations (Table 2). There is some evidence that openings contain soils that differ from those below trees, reflecting long-term vegetation influences on soil development (White 1985, Kerns et al. 2003). Switching the locations of these patches in current forests may have unforeseen influences on herbaceous productivity or other variables.

Understory Vegetation. Much of the species diversity in ponderosa pine forests is contained in understory vegetation, which also provides forage for herbivores (Moore et al. 1999). Understory biomass can be >10 times higher in remnant and restored openings than even under sparse ponderosa pine canopy cover (Clary 1975). These overstory-understory relationships illustrate a tradeoff: retaining extra trees because of diameter caps decreases understory productivity and diversity (Table 2).

Large Pine and Snags. Large pine and snags are important habitat features for many wildlife species (Ganey and Vojta 2004). Diameter caps may increase or maintain densities of large pine and snags, at least in the short term, after thinning (Table 2). However, consideration also needs to be

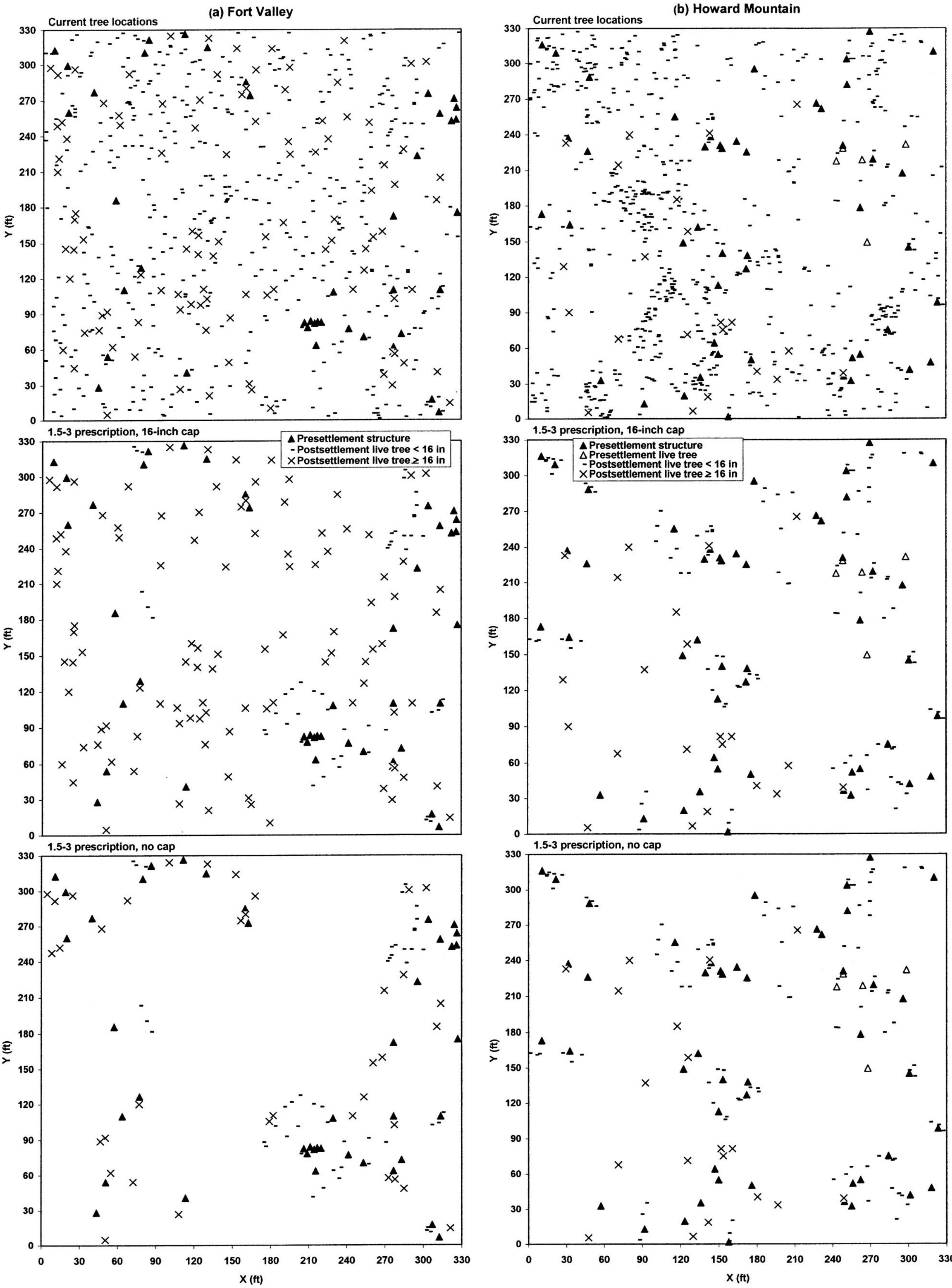

Figure 2. Stem maps showing distributions of ponderosa pine in 2004 (current) and after a simulated 1.5–3 restoration thinning prescription with and without a 16-in.-diameter cap. (a) High densities (42/ac) of ≥16-in. postsettlement trees limit reestablishment of meadows under any thinning prescription with a 16-in. cap. (b) Sixteen-in. caps have little influence on postthinning structure because the site contains few ≥16-in. trees. Plots were mapped on the Coconino National Forest, northern Arizona (panel a: 35°15′50″ N, 111°40′42″ W; panel b: 35°02′30″ N, 111°38′33″ W).

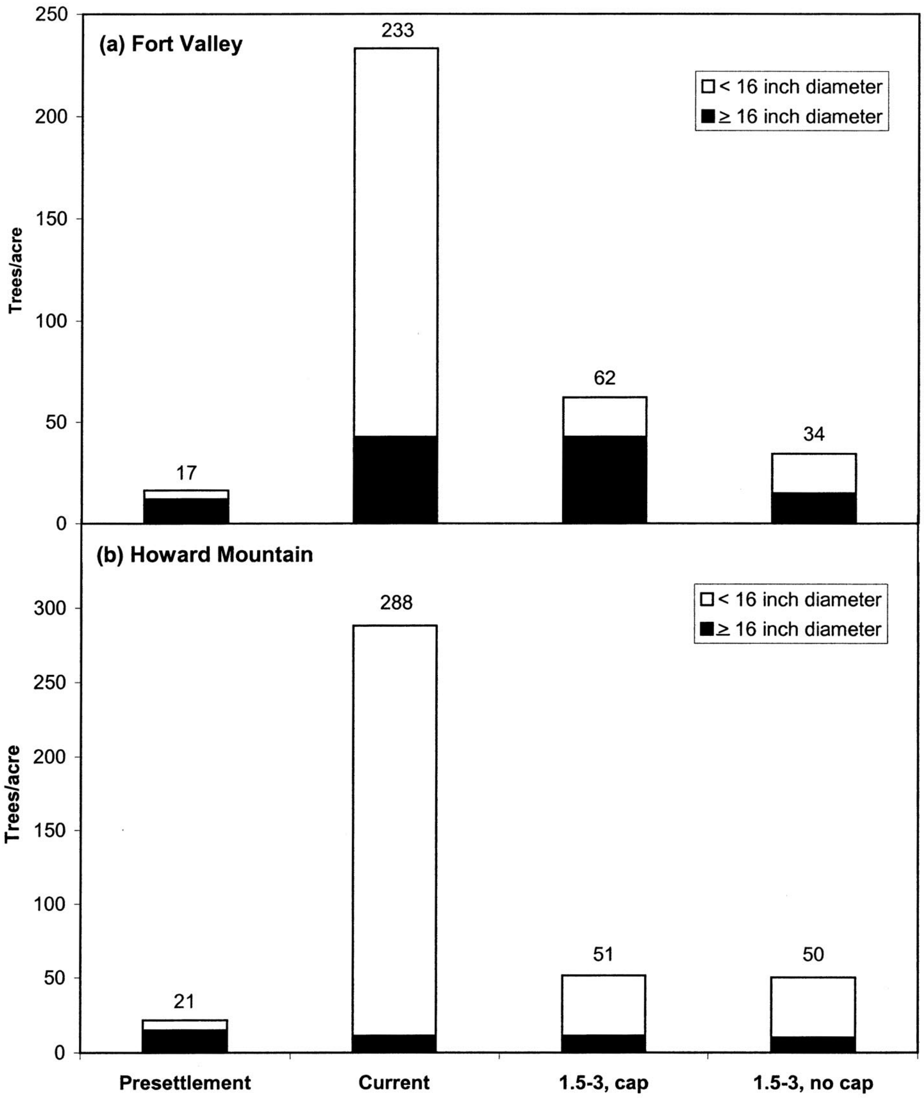

Figure 3. Tree densities corresponding with stem maps in Figure 2. Total trees per acre is shown at the top of each bar. The presettlement category represents tree densities at the time of fire exclusion after Euro-American settlement in approximately 1880. (a) A 16-in.-diameter cap nearly doubled the tree density remaining after a simulated restoration thinning prescription. (b) In contrast, a cap altered residual density by only one tree per acre because the plot contained few ≥16-in. postsettlement trees (nine per acre). There were no living presettlement-origin trees in panel a, while panel b contained two live presettlement trees per acre, which were >16 in. in diameter.

given to how limiting snag densities are to wildlife populations and what species may be limited by snag availability. For example, Brawn and Balda (1988) concluded that only three of six cavity-nesting bird species they studied in northern Arizona ponderosa pine forests were limited by nest-site availability in snags. Food and foraging substrate, which often decrease with increasing pine densities (Clary 1975, Waltz and Covington 2004), may more strongly limit bird densities on some sites.

Wildlife Habitat. Diameter caps may influence wildlife by affecting stand structure and other variables impacted by this structure such as understory vegetation and mast-producing Gambel oak (*Quercus gambelii*). Caps probably will promote wildlife species benefiting from higher pine densities, while negatively impacting species dependent on open forests. For example, Dodd et al. (2003) found that tassel-eared squirrels (*Sciurus aberti*) in northern Arizona ponderosa pine forests were more abundant in stands with high densities of interlocking canopy trees. On the other hand, these stands constitute poor habitat for species dependent on open-forest features, such as high solar radiation and understory productivity. Maintaining open stands is consistent both with ecosystem-based (rather than single species) management and the evolutionary environments many wildlife species encountered in historical ponderosa pine forests (Moore et al. 1999).

Pine Autecology. Diameter caps could have no effect, negative effects, or positive effects on pine variables such as genetics and regeneration (Table 2). Thinning reduces tree population sizes, which may decrease genetic diversity. However, Kolanoski (2002) found that much of the genetic diversity of ponderosa pine at a northern Arizona site was related to differences in tree ages and establishment periods. Many post-settlement 16-in. trees are similar age and originated under similar conditions shortly after Euro-American settlement. It is possible that thinning these 16-in. trees to create regeneration opportunities for new cohorts would increase genetic diversity for establishment in current environmental conditions. However, different findings in other regions suggest that additional research is needed for clarification (Linhart et al. 1981). Another consideration is whether the episodic timing of natural regeneration of ponderosa pine can meet desired levels in post-thinning forests. Bailey and Covington (2002) evaluated regeneration rates after several tree thinning and prescribed burning projects in northern Arizona and concluded that regeneration rates were sufficient or exceeded those needed to maintain presettlement tree densities. It is unclear if regeneration might be more or less prominent in other regions. In areas where regeneration is deficient, caps might be used to increase seed sources, but they also may decrease densities of regeneration microsites if litter accumulates in the absence of burning. Many additional factors warrant consideration, such as potential impacts of caps on density-dependent tree-damaging agents such as insect outbreaks.

Timber Production. Although diameter caps decrease timber production in the short term, they probably increase the growing stock in the long term. Caps can result in evenly spaced stands of young, rapidly growing trees (Figure 2a). Skov et al. (2005) found that growth of 80-year-old residual ponderosa pines increased within 1 year after thinning in northern Arizona, suggesting that 16-in. trees left by caps grow quickly. Ironically, a major reason cited to support caps is that timber production and eco-

Table 2. Anticipated effects of diameter caps on several ecosystem components and economics in southwestern ponderosa pine forests. Effects can be chiefly positive (+), neutral (0), or negative (−).

Variable	Effect	Example reference
Canopy openings	−	Moore and Huffman 2004
Understory vegetation	−	Clary 1975
Large pine and snags	+ or 0	Ganey and Vojta 2004
Wildlife habitat	+, 0, or −	Dodd et al. 2003
Pine autecology	+, 0, or −	Kolanoski 2002
Timber production	+ or 0	Skov et al. 2005
Gambel oak vigor	−	Onkonburi 1999
Soil microorganisms	−	Boyle et al. 2005
Nutrient cycling	−	Kaye and Hart 1998
Invertebrates	+, 0, or −	Waltz and Covington 2004
Water relations	−	Brown et al. 1974
Fire behavior	0 or −	Fulé et al. 2001
Economics	−	Larson and Mirth 2004

nomic returns from selling large postsettlement trees should not drive restoration and fuel reduction projects (Table 1). On some sites, caps may necessitate major sawtimber harvests in the future to again reduce wildfire risks and improve ecosystem health (e.g., Figure 2a). However, depending on residual stand density and stem spacing, caps also could result in increased competition and slowed growth of both young and old trees (Skov et al. 2005).

Gambel Oak Vigor. As one of only a few deciduous trees in ponderosa pine forests, Gambel oak constitutes an important habitat feature for many wildlife species by providing acorns and cavities (Reynolds et al. 1970). Large-diameter oaks have unique values, and pine thinning may increase oak growth to speed the recruitment of large oaks (Onkonburi 1999). However, diameter caps may constrain thinning postsettlement pine around oaks, slowing oak growth and hastening declines of old oaks (Onkonburi 1999).

Soil Nutrient Cycling and Microorganisms. Kaye and Hart (1998) found that canopy openings had annual net N mineralization rates twice as high as those below retained postsettlement trees 2 years after thinning in northern Arizona. Similarly, Boyle et al. (2005) reported that during dry periods, soil respiration rates were 33% greater in canopy openings than below postsettlement trees. These studies suggest that maintaining stands of high tree density may slow soil nutrient cycling and microbial activity, possibly decreasing long-term soil productivity (Boyle et al. 2005).

Invertebrates. In northern Arizona, Waltz and Covington (2004) found that butterfly richness and abundance were two to three times greater in restoration (thinned + burned) units than in paired control units 2 years after treatment. These increases primarily resulted from increased sunlight, which can affect butterfly flight durations and patterns (Waltz and Covington 2004). Retaining additional trees because of diameter caps consistently reduces solar radiation reaching the ground. However, habitat requirements of invertebrate species vary widely and some species using pine litter or otherwise strongly associated with pine may benefit from diameter caps. As a result, caps may have positive, negative, or no effects on invertebrate species, and it remains unclear how caps may affect the invertebrate community as a whole.

Water Relations. On the Beaver Creek watershed in Arizona, Brown et al. (1974) monitored streamflow for 4 years after a thinning using group selection removed 75% of basal area. Thinning increased streamflow on average 22% per year, while a grazing treatment (60% use of perennial grasses) increased streamflow only 8%. Reducing tree densities, therefore, enhanced streamflow more sharply than reducing herbaceous vegetation. Correspondingly, it is unlikely that diameter caps will increase streamflow, and they may decrease flow because of increased tree canopy interception and water use.

Fire Behavior. We estimated foliar biomass following Kaye et al. (2005) for the mapped plots in Figure 2. Fine-canopy fuels, especially foliage, comprise the fuel that carries crown fire. Although the vertical and horizontal arrangement of these fuels is also important, foliar biomass is directly linked to canopy bulk density and crown fire behavior (Cruz et al. 2003). On a plot containing a high density of ≥16-in. trees (Figure 2a), only 21% of foliar biomass remained after simulated restoration thinning without a cap, compared with 51% remaining after cap-constrained thinning. In contrast, residual foliar biomass was only 4% greater with a cap than without a cap after simulated thinning on a plot containing few ≥16-in. trees (Figure 2b). Because reducing crown fire hazard is currently a part of management plans for many thinning projects in western forests, careful consideration should be given to whether this objective is met with a diameter cap. Focus should not be restricted to stand conditions immediately after thinning and should include the potential for canopy ingrowth.

Economics. Small-diameter ponderosa pine logs have little economic value, and economics is one of the major factors limiting the implementation of thinning projects (Lynch et al. 2000, Larson and Mirth 2001). Larson and Mirth (2001) modeled the economic effects of 16-in. caps on a northern Arizona thinning project. Caps reduced net profits of thinning contractors by a projected 22–176%, which resulted in net losses to contractors in some units. While markets for ≥16-in.-diameter logs vary geographically and through time, caps likely negatively impact contractor availability and the economics of thinning projects by reducing the size of logs produced (Larson and Mirth 2001). Furthermore, selling some postsettlement ≥16-in. trees might generate forest products and funds that could be used for postthinning management, such as exotic species control, seeding native species, and prescribed burning (Fiedler et al. 1999).

In summarizing tradeoffs of caps, a central tenet in ecology is that resources are limited in ecosystems. Retaining additional trees inevitably decreases resources available to many other organisms. Most modern ponderosa pine forests are vulnerable to catastrophic change precisely because ecosystem biomass dramatically shifted toward ponderosa pine after tree density irruptions in the late 1800s (Covington et al. 1997, Allen et al. 2002). Diameter caps appear most useful for maintaining high densities of young, large trees immediately after thinning, creating habitat for specific species (e.g., tassel-eared squirrels) favored by high tree densities and sustaining a large timber base (Table 2). Based on published research, diameter caps will not improve and will likely negatively impact canopy openings, understory productivity, Gambel oak vigor, soil microorganisms, nutrient cycling, streamflow, fire behavior, and the economics of thinning projects.

Conclusions

Our analysis revealed the following six major considerations about the use of 16-in.-diameter caps in thinning projects. First, prethinning densities of ≥16-in. trees determine the magnitude of the effects that caps have on postthinning tree structure and ecosystem components affected by trees. Second, caps can result in switching the locations of tree and meadow patches from their historical locations. However, caps may be useful to take advantage of existing tree structure to rapidly reestablish groups of large trees, if maintaining meadow locations is not an objective (Allen et al. 2002). On the other hand, caps may result in slowed tree growth, depending on residual stand density and stem spacing. Third, caps are a one-size-fits-all policy, which seems at odds with the diversities of sites and management objectives in western forests. This observation underscores that informed policies about caps should consider desired future stand conditions defined by management objectives and whether or not these conditions are best met with cap-free or cap-constrained thinning.

Fourth, maintaining high tree densities means fewer resources are available for ecosystem components dependent on open stand structures, which characterized most evolutionary environments in southwestern ponderosa pine forests (Moore et al. 1999). Fifth, evaluations of diameter caps should not be restricted to conditions immediately after thinning. Trees grow, and effects of future canopy ingrowth should be considered. Sixth, we suggest that a reasonable evaluation of the tradeoffs of diameter caps include whether or not a cap-constrained thinning project on a specific site establishes canopy openings and reduces crown fire hazards. If these key objectives are not met, thinning projects may have limited benefit for ecosystem health or for the safety of human settlements in fire-prone western forests. Caps can affect the trajectory and the magnitude of ecosystem change after thinning, with resulting ecosystem characteristics sometimes differing substantially between thinning with or without caps (Fulé et al. 2006). Although our analysis focused on southwestern ponderosa pine forests, similar assessments of the tradeoffs of diameter caps may be applicable in other forest types for making informed policy and management decisions.

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